Modeling of Sediment Mechanics for Mine Burial Prediction

Horst Brandes
Ron Riggs
Department of Civil Engineering
University of Hawaii
2540 Dole Street
Honolulu, HI 96822
phone (808) 956-8969, fax (808) 956-5014, email brandes@wiliki.eng.hawaii.edu

Award number: N00014-01-1-0513
http://www.eng.hawaii.edu/CE/

LONG-TERM GOALS

The long-term goal of the project is to understand and model the burial of mines and similar objects into the seabed due to processes of liquefaction and mine-induced local sediment deformation.

OBJECTIVES

The specific objectives of this study are:

- Develop a numerical procedure for modeling mine burial as a time-dependent process with a focus on sub-seabed liquefaction and sediment mechanics.

- Collect necessary material parameters, including pore pressure generation characteristics under cyclic loading conditions, from planned field and laboratory tests.

- Integrate findings from this study with parallel modeling efforts underway as part of ONR's Mine Burial Program (MBP), which are exploring burial processes due to bedform migration and local scour.

APPROACH

The numerical model under development is based on Biot's physically consistent theory of consolidation for poro-elastic media. The objective has been to incorporate all the important aspects of sediment mechanical behavior that play a role in the sinking of mines, including pore fluid diffusion, shear and volume deformation according to elastic or higher-order constitutive models, and time dependency of pore pressures and stresses. Since the eventual application of the model will involve problems with complex domains and boundary loads, and possibly non-uniform material distributions, it is necessary that the fundamental equations be framed in numerical terms in order to solve them and make predictions of mine burial. The finite element method is the technique of choice in soil mechanics for these types of problems and has been chosen for this study. Two models are currently under development, MINE-B and GEO-CP. Development of these new codes is necessary since we intend to incorporate a number of behavioral aspects that are not routinely accounted for in commercial codes. These include the accumulation of excess pore pressures and accompanying settlement due to

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **Modeling of Sediment Mechanics for Mine Burial Prediction**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Department of Civil Engineering,University of Hawaii,,2540 Dole Street,,Honolulu,,HI, 96822**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The long-term goal of the project is to understand and model the burial of mines and similar objects into the seabed due to processes of liquefaction and mine-induced local sediment deformation.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

cyclic loading of the seabed from surface water waves, changes in stiffness that are likely to occur as the sediment undergoes permanent deformations, and large displacements and potential re-suspension of seabed material.

WORK COMPLETED

ONR's Mine Burial Program is an ambitious long-term program. However, no field experiments have yet taken place and our work so far has concentrated on code development, validation, and preparation of preliminary liquefaction charts. Our efforts have resulted in two publications that are listed at the end of this report.

Future work will include the refinement of the current formulation to allow for the mechanism of long-term pore pressure generation. This requires experimental data for representative seabed sediments. We have just acquired a state-of-the-art laboratory simple shear device with which we intend to investigate pore pressures, stiffness and overall cyclic response. The contemplated experimental work should lead to improvements in the existing constitutive model. Code development efforts will focus on improving the capabilities of the finite element programs and on developing interfaces for input of variable seabed loads from real wave records and from processes associated with sediment erosion or deposition. The intention is not to incorporate the mechanics of such processes directly, but instead to consider the consequences of the associated changes in seabed elevation on subsurface stresses and hence mine burial.

RESULTS

As a necessary part of code development, we have selected a simple 2-D case study for model validation for which analytical expressions for stresses and strain exist. The problem consists of a uniform seabed of linearly elastic sand with a single sinusoidal surface water wave propagating along the sea surface. Linear wave theory is assumed. These conditions allow the development of exact expressions for plane strain stresses, strains and excess pore pressures in the subseabed (Yamamoto et al., 1978; Madsen, 1978; Sakai et al., 1992). Granted this represents an overly simplistic modeling approach for most practical settings, it does allow for validation of the finite element codes and for the development of preliminary liquefaction charts for predicting the extent of momentary liquefaction as a function of water depth and wave characteristics. The depth to which liquefaction is predicted may correlate with mine burial, since by definition, a liquefied seabed cannot support any object whose weight is larger than that of the sediment. These charts can be adapted for use in upcoming field experiments.

An example of such a chart is illustrated in Figure 1, which can be used to predict the depth of momentary liquefaction below the seabed that occurs under the crest of single linear waves of given characteristics. The conventional criteria for the onset of liquefaction proposed by Seed and Lee (1966) is used here:

$$p/(\gamma' z) \geq 1.0 \tag{1}$$

which states that liquefaction will occur when the ratio of excess pore pressure p exceeds the effective overburden stress (γ'=10 kN/m^3 in this study and z is distance below seabed).

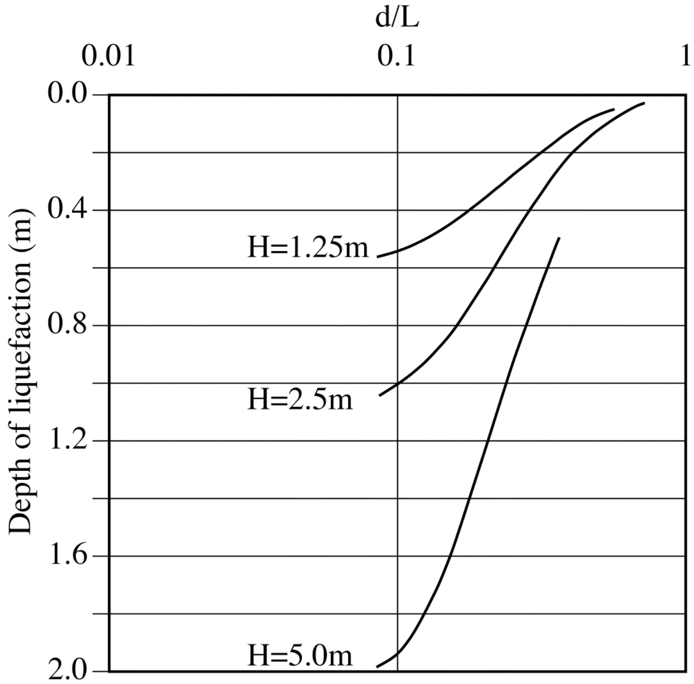

Figure 1. Predicted depth of liquefaction below seabed for single, linear surface wave (d=water depth, L=wave length, H=wave height. Period T is given by linear wave theory)

The code MINE-B was used to solve the same problem of a single, linear wave propagating over a 2-D seabed. A specific wave with a wave length of 48 m, a period of 6 seconds, and a wave amplitude of 2.4 m was chosen. Computed excess pore pressures after 150 wave cycles are illustrated in Figure 2. The results are expressed in terms of excess pore pressure ratio, i. e. pore pressure divided by seabed pressure amplitude. As expected, excess pore pressures dissipate with depth and maximum values are found below the crest of the wave. The MINE-B results are compared to the exact solution in Figure 3 for a location directly below the crest of the wave. The agreement between the theoretical and calculated predictions is good indeed. This suggests that the MINE-B code gives reasonable predictions and that we have selected appropriate space and time scales, along with proper boundary loads and fixities. Additional details on the modeling can be found in Brandes and Riggs (2002).

IMPACT/APPLICATIONS

Results from our modeling clearly suggest that there may exist scenarios in the field where one can expect bearing capacity loss, and hence mine burial, due to wave-induced excess pore pressure leading to partial or full seabed liquefaction. Mine sinking is clearly a phenomena associated with changes in stresses below the seafloor, which need to be considered if any reasonable mine sinking estimates are to be obtained. The additional process of long-term liquefaction due to volume reduction that can occur in loose sandy deposits due to multiple wave cycles still needs to be accounted for in order to arrive at a model that is able to make accurate predictions. This work is currently underway.

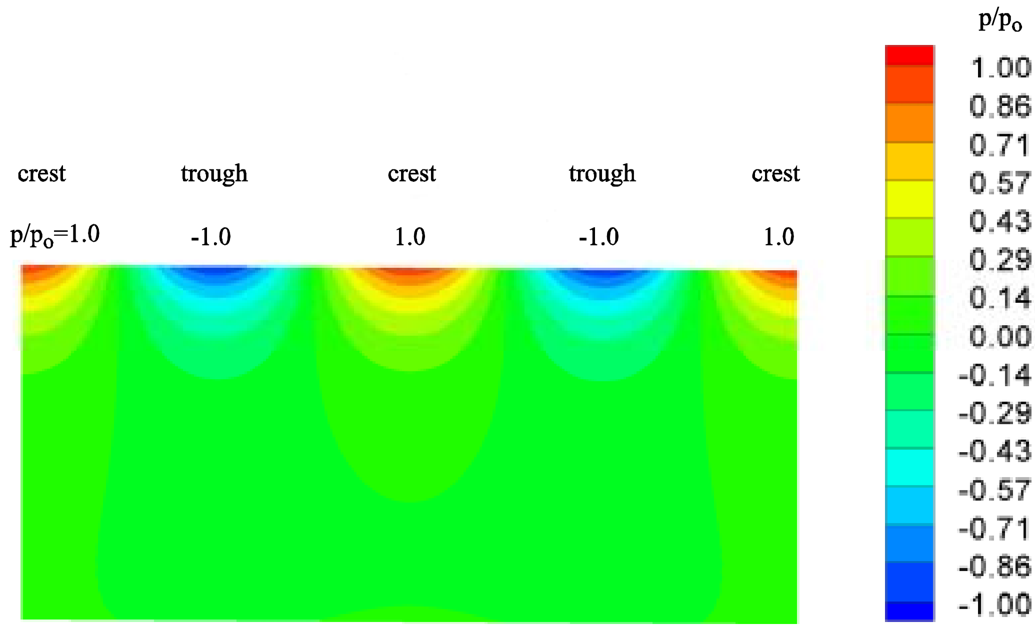

Figure 2. Excess pore pressure in 2-D seabed deposit after 150 wave cycles

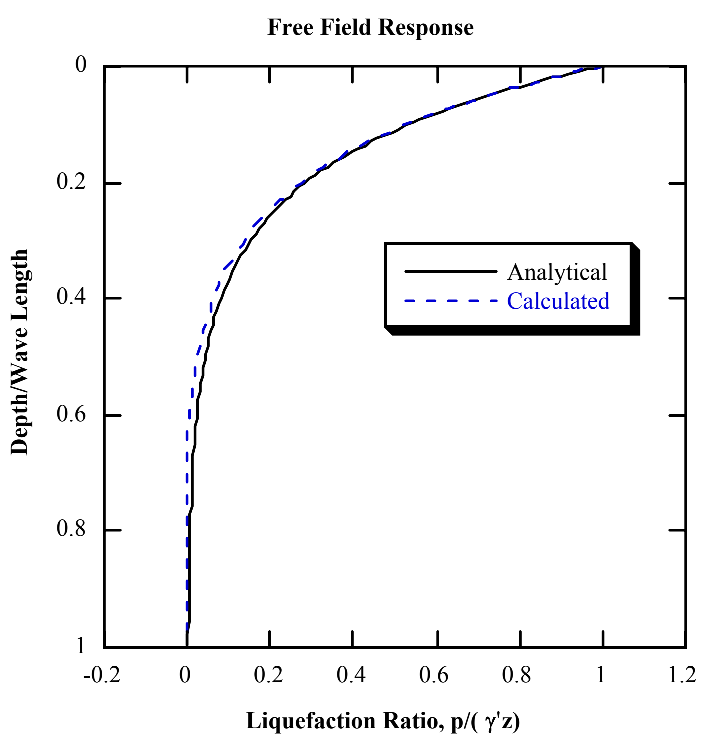

Figure 3. Calculated versus predicted pore pressure ratio below crest of wave

TRANSITIONS

The code under development will be made available to researchers of the Mine Burial Program and others. With suitable further development, it may also be useful for military decision-making purposes.

RELATED PROJECTS

We intend to interact with other researchers in the Mine Burial Program as we continue to refine our modeling efforts. In particular, Dr. Scott Jenkins at Scripps has agreed to provide information on time series describing scour geometries surrounding mines, as well as hydrodynamic mine loads, which we will use as input to our program. Similarly, Dr. C. C. Mei at M.I.T. has agreed to help develop time series that describe bedform migration processes. This type of input, as well as information regarding in situ sediment properties and pore pressure characteristics, will become available as data is collected from various planned field experiments.

REFERENCES

Brandes, H. G. and Riggs, H.R. (2002). Modeling of seabed liquefaction and other processes responsible for mine burial. *Proceedings of OMAE'02, 21st International Conference on Offshore Mechanics and Arctic Engineering*, OMAE2002-28242, pp. 1-8.

Madsen, O. S. (1978). Wave-induced pore pressures and effective stresses in a porous bed. *Geotechnique*, 28(4):377-393.

Sakai, T., Hatanaka, K. and Mased, H. (1992). Wave induced stresses in seabed and its momentary liquefaction. *Journal of Waterways, Port, Coastal and Ocean Engineering, ASCE*, 118(WW2):202-206.

Seed, H. B. and Lee, K. L. (1966). Liquefaction of saturated sands during cyclic loading. *Journal of the Soil Mechanics and Foundations Division, ASCE*, 92(SM6):105-134.

Yamamoto, T., Koning, H. L. and Hijum, E. V. (1978). On the response of a pro-elastic bed to water waves. *Journal of Fluid Mechanics*, 87(1):193-206.

PUBLICATIONS

Brandes, H. G. and Riggs, H.R. (2002a). Modeling of seabed liquefaction and other processes responsible for mine burial. *Proceedings of OMAE'02, 21st International Conference on Offshore Mechanics and Arctic Engineering*, OMAE2002-28242, pp. 1-8.

Brandes, H. G. and Riggs, H.R. (2002b). Numerical modeling of seabed liquefaction due to surface water waves. *Proceedings of the 12th International Offshore and Polar Engineering Conference*, 2:558-562.